THE ROLE OF PHYSICAL LITERACY IN THE DEVELOPMENT OF MOTOR COMPETENCES AND COGNITIVE FUNCTIONS AMONG SCHOOL-AGE CHILDREN

IL RUOLO DELL'ALFABETIZZAZIONE FISICA NELLO SVILUPPO DELLE COMPETENZE MOTORIE E DELLE FUNZIONI COGNITIVE DEI BAMBINI IN ETÀ SCOLARE

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ABSTRACT
The engagement in physical activity (PA) throughout childhood significantly contributes to cognitive, social, and physical development of children. To foster sustained participation in physical activity, school has been identified as optimal environment for promoting an active lifestyle and mitigating sedentary tendencies while enhancing children's cognitive capabilities. The aim of the current investigation was to examine the efficacy of a Physical Activity program focused on physical literacy (PL) on the enhancement of motor competence and cognitive function among children. The results show that PL promotes the cognitive, motor and social skills needed to engage in physical activities and achieve academic success.

La pratica dell'attività fisica (PA) durante l'infanzia contribuisce in modo significativo allo sviluppo cognitivo, sociale e fisico, influenzando così la salute dei bambini. Al fine di favorire la partecipazione all'attività fisica, la scuola è stata identificata come l'ambiente ottimale per promuovere uno stile di vita attivo e mitigare le tendenze sedentarie, migliorando al contempo le capacità cognitive dei bambini. L'obiettivo della presente indagine è stato quello di esaminare l'efficacia di un programma di attività fisica incentrato sull'alfabetizzazione motoria (PL) sul miglioramento delle competenze motorie e delle funzioni cognitive nei bambini. I risultati dimostrano che la PL permette di promuovere le competenze cognitive, motorie e sociali necessarie per impegnarsi in attività fisiche e raggiungere il successo scolastico.

KEYWORDS
Academic achievement; pedagogy; motor and cognitive development.
Risultati accademici; pedagogia; Sviluppo motorio e cognitivo.

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Introduction

The practice of physical activity (PA) during childhood promotes cognitive, social and physical development and influences children's present and future health (Zeng et al., 2017). Despite its benefits, the data regarding the practice of physical activity, both in Europe and in Italy, are not at all satisfactory. The percentage of children who comply with the World Health Organization's (WHO, 2020) recommendation to engage in at least 60 minutes of moderate to vigorous physical activity per day is alarmingly very low. This situation causes a decline in basic motor skills and cognitive functions, the repercussions of which manifest themselves in daily life.

To enhance compliance with these guidelines, educational institutions have been identified as optimal settings for fostering physical activity (PA) and diminishing sedentary behavior while concurrently enhancing children's cognitive capabilities. Indeed, students allocate a significant portion of their day (approximately 7-8 hours) within the school environment. Engagement in PA during academic hours is correlated with variables such as attention, cognitive abilities, and scholastic achievement (Sember, Jurak, Kovač, Morrison, & Starc, 2020).

It is now acknowledged that school is pivotal to the cultivation of students' physical literacy, which encompasses motivation, safety, physical proficiency, knowledge, understanding of assessment, and the assumption of responsibility for lifelong engagement in physical activity. School physical education frequently represents the sole organized environment wherein children can engage in motor activities that are intrinsically linked to semantic and logical frameworks associated with other areas of learning (Haverkamp et al., 2020). This domain plays a crucial role in the overarching educational trajectory of individuals by fostering an enhanced awareness of the corporeal self, facilitating the acquisition of motor competencies, and expanding both the quantitative and qualitative avenues for engaging in motor experiences, wherein students are comprehensively engaged not solely on a physical-motor dimension but also on cognitive, emotional, and social planes (Dapp, Gashaj, & Roebers, 2021). Specifically, physical education aids in the development of a personal repertoire of motor skills that are essential for holistic individual development, while simultaneously serving as a nexus that interconnects various academic disciplines. Indeed, the experiences derived from corporeal engagement and motor activities establish both the foundational basis (perceptual activities) and the transitional pathway (executive functions and processes of motor coordination) for the entirety of the learning process (Colella, 2018).

The promotion of Physical Literacy (PL) has been recognized as a pivotal opportunity to yield considerable health advantages across various age groups, while also fostering both specific and transversal learning (Whitehead, 1993). Beyond its fundamental physical implications, physical literacy encompasses the

interconnected physical, psychological, social, and cognitive dimensions. A Physical Education curriculum centered around PL possesses the capacity to enhance not only students' levels of physical activity and motor competence but also to augment facilitators of learning such as concentration, cognitive function, time allocated to tasks, as well as executive functions and overall academic achievement.

Physical Literacy, indeed, serves as a comprehensive construct of motor competence: a compilation of skills, both declarative and procedural knowledge, attitudes, and dispositions of individuals that can be manifested across diverse contexts (Colella, 2016). Simultaneously, this foundational alphabet is integrative with other forms of literacy, such as logical-mathematical reasoning, writing, and artistic expression. Consequently, the enhancement of motor skills contributes to the improvement of cognitive control and organizational capabilities.

In this context, the emphasis on which focus must be directed towards the advancement of motor skills pertains to the executive variants: components that integrate motor patterns, thereby facilitating their transfer across diverse contexts. Motor literacy, and consequently the development of children within the realm of motor activities, is contingent upon its contribution to other domains of the individual. This aspect is not incidental but rather deliberate, necessitating that educators possess the capacity to influence all facets of the individual.

Nevertheless, to date, a limited number of investigations have been conducted to elucidate how physical literacy (PL) can confer advantages, not solely in terms of the quantity of physical activity engagement, but also in other dimensions pertinent to the motor and academic progression of children. The primary objective of the current study was, therefore, to examine the potential impact of PL on the enhancement of motor skills and cognitive functions in children.

1. Methods

Study design and participants

The research was designed as a randomized controlled trial (RCT) employing a two-arm randomized, parallel-group methodology to examine the impacts of a physical literacy-focused physical education curriculum on first-year students from two lower secondary educational institutions. In this research endeavor, the schools were designated as the units of randomization, while the students served as the units of analysis.

The examination extended over an 8-week period (60 minutes, twice per week), during which participants were randomly assigned to either the experimental group or the control group. A systematic review conducted by Norris and collegues (2020) suggested that if the intervention duration exceeds 8 weeks and the cumulative volume of activities in minutes is less than that stipulated in the

current investigation, the immediate effects on several key variables (such as physical activity or academic achievement) may be diminished. Additionally, a recent school-based intervention (Kelly, O'Connor, Harrison, Chéilleachair, 2020) carried out over 8 weeks demonstrated favorable outcomes regarding motor competence.

As a convenient sampling method, a cohort of one hundred students was selected, exhibiting an age range of 10 to 11 years (M age = 10.75, SD = ± 0.46), to engage in the study. Participation was entirely voluntary, with all first-grade students deemed eligible to partake in this research endeavor. The subsequent inclusion criteria were delineated to form a convenient sample that would adequately address the objectives of the study: children enrolled in the designated schools, relatively healthy individuals capable of undertaking an exercise regimen, and those able to refrain from alternative physical pursuits, in accordance with the study's protocol. A priori power analyses indicated that a sample size of n = 57 within each group would be sufficient to adequately power the study, allowing for the detection of a medium effect size (f= 0.25 or 0.4) with a coefficient of correlation of p=0.80, achieving 95% power, and establishing a significance level at $\alpha = .05$. To mitigate potential attrition, larger samples were subsequently recruited.

In alignment with the inclusion criteria, 100 subjects were solicited to participate in the study. All students consented to engage in the research study and successfully completed the preliminary measurements. Consequently, the final sample comprised 100 participants, who were matched and assigned at random to one of two treatment conditions. The experimental group (EG) (n = 100) engaged in the physical literacy (PL) program, whereas the control group (CG) (n = 100) continued to attend traditional physical education classes, focusing on fundamental motor skills, body expression, physical activity and health, as well as sports and games. The school principals were duly informed regarding the study. Subsequent to the principals' approval, written informed consent was obtained from all participating parents, who were assured they could withdraw their consent at any point. The researchers conducted the study in accordance with the Declaration of Helsinki, ensuring that all data were collected in an anonymous manner.

Procedures

The intervention program was conducted during the standard school days within the confines of the school gymnasium. Standardized assessments of motor skills and mathematical performance were evaluated prior to and subsequent to the intervention phase in order to ascertain the initial capabilities of the participants and to identify any alterations in performance relative to the baseline measurements. Consequently, the data collection methodology was systematically categorized into three distinct phases: pre-test, intervention, and post-test.

The participants undertook each assessment at a consistent time of day and under uniform experimental conditions. Testing was administered on an individual basis, with a comprehensive explanation of each task provided prior to the commencement of the assessments. The children were kept uninformed of the study's objectives or the experimental conditions to mitigate any potential biases that could compromise the integrity of the data. Participants were mandated to don appropriate athletic attire to minimize variability throughout the testing procedures and were advised to refrain from engaging in strenuous physical activity 24 hours prior to each assessment session. All testing measurements, as well as the implementation of both intervention programs, were directed, overseen, and executed by two proficient Physical Education instructors, duly certified by the Italian Ministry of Education.

Measurements

Motorfit

The gross motor development test (Perotta, Corona, & Cozzarelli, 2011) is an individually administered test, which assesses the gross motor function of children between the ages of 3 and 10/11 years. The test measures 6 gross motor skills that are frequently taught with school-age children (primary school and first classes of lower secondary school) each of which assesses a different aspect of gross motor development: locomotion and object control.

AC-MT 11-14 test

The AC-MT 11-14 (Cornondi, 2020) represents a rigorously validated assessment tool that facilitates a standardized and comprehensive evaluation of both arithmetic problem-solving and arithmetic reasoning capabilities. It is structured into two distinct segments known as the Collective part focusing on numbers and calculations, and the Problem Solving segment. These segments necessitate collective administration and encompass knowledge pertaining to numerical concepts, arithmetic reasoning, and problem-solving methodologies. Concerning the initial segment, it comprises eight subtests (performing operations, arithmetic expressions, identifying the largest value, transforming into numerical form, completing sequences, transcribing into numerical format, approximate calculations, as well as facts, procedures, and principles) and can be categorized into three macro-variables, specifically written calculation, comprehension and production, and arithmetic reasoning.

The duration allocated for the first segment is approximately 60 minutes, while the second segment requires around 30 minutes (inclusive of instructions and practice phases). The scoring system is designed to allocate one point for each correct response and zero points for each incorrect response.

PL intervention

To devise an intervention targeted at children aged 10 to 11 years, grounded in the concept of Physical Literacy, we executed a meticulously crafted intervention program that was explicitly engineered to align with the logistical and temporal constraints of the designated educational institutions. This program was implemented biweekly over an 8-week period within the established Physical Education curriculum, extending for a duration of 60 minutes. Within the parameters of this intervention, each session methodically incorporated explicit references to all dimensions of Physical Literacy (Fig. 1), in accordance with the recognized definition and conceptual framework of Physical Literacy (Agans, Stuckey, Cairney, & Kriellaars, 2024). Specifically, it encompassed the physical, cognitive, emotional, and social spheres. In alignment with the principles articulated by Whitehead (Whitehead, 2019), who underscored the significance of providing a diverse array of content to foster children's enthusiasm for engaging in physical activity, this program included a comprehensive variety of physical pursuits throughout the intervention, as Physical Literacy advocates for participation in a wide range of physical activities and for empowering individuals to interact with their own physical capabilities (Carl et al., 2022). Consequently, it comprised rule-governed games, aesthetic movements, interactions with and on apparatus, ball games, and fundamental forms of physical fitness (Caldwell et al., 2022). Furthermore, the distinctions (taxonomies) between locomotor skills and object control, as well as individual versus team activities, were integral to the intervention, thereby incorporating a diverse set of movement modalities and experiences. The program predominantly concentrated on terrestrial activities, as aquatic endeavors could not be undertaken due to logistical, pragmatic, and legal considerations.

The Physical Literacy intervention was structured to include a preparatory phase of 10 minutes, followed by a primary session lasting 40 minutes, and concluding with a recovery phase of 10 minutes. During the core session, a variety of activities were executed with the aim of enhancing engagement, motivation, and enjoyment. Evidently, the fitness regimen was developed to be both enjoyable and attractive, with the intention of fostering a comprehensive understanding of one’s potential.

The control group engaged in conventional curricular physical education sessions that featured activities (predominantly team sports) deliberately selected by the teacher.

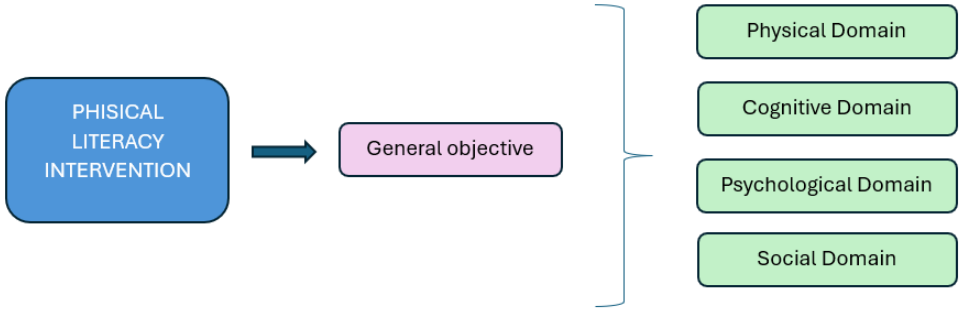

Fig. 1 - Physical Literacy intervention: diagram flow.

2. Statistical Analysis

Statistical analyses were performed utilizing IBM SPSS (version 25.0, developed by IBM in Armonk, NY, USA). The data were represented through group mean (M) values accompanied by standard deviations (SD). The evaluation of normality assumptions was conducted employing the Shapiro–Wilk test, while the assessment of homogeneity of variances was executed through the Levene test. The examination of group differences at baseline was conducted employing an independent sample t-test. The impact of the exercise regimen on dependent variables was analyzed through a two-way ANOVA (group (experimental/control) × time (pre/post-intervention)) involving repeated measures across the temporal dimension. In instances where significant 'Group × Time' interactions were identified, paired t-tests were performed to elucidate significant differences. The effect size of the prominent 'Time × Group' interaction was assessed using the partial eta squared ($\eta 2p$) statistic, with classifications denoting small ($\eta 2p < 0.06$), medium ($0.06 \leq \eta 2p < 0.14$), and large ($\eta 2p \geq 0.14$). Furthermore, Cohen's d (1992) was employed for the evaluation of effect sizes in pairwise comparisons, with classifications of small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.79$), and large ($d \geq 0.80$). Statistical significance was established at $p < 0.05$.

3. Results

Each individual involved in the study was exposed to the designated therapeutic parameters, and there were no documented occurrences of injuries among participants throughout the entirety of the trial period. The individuals participating in the investigation did not disclose any significant variations concerning age, gender, anthropometric indices, psychological assessments, or socioeconomic status ($p > 0.05$). The results pertaining to all dependent variables are presented in Table 1.

Table 1 - Changes after 8-week PL intervention.

	Experimental Group (n = 100)			Control Group (n = 100)		
	Baseline	**Post-test**	**Δ**	**Baseline**	**Post-test**	**Δ**
Motorfit						
Motorfit Locomotor	8.76	9.59 (1.04)	0.82	8.79	9.30	0.51
Motorfit Object	8.24	9.49 (1.02)	1.25	8.56	9.28	0.72
AC-MT 11-14 Test						
Written calculation	5.77	5.57 (2.20)	-0.20	6.74	5.49	-1.24
Comprehension and	14.01	15.85 (2.80)	1.84	15.07	14.15	-0.92
Arithmetic reasoning	21.33	23.30 (3.03)	1.96	22.66	22.16	-0.49
Problem solving	6.20	7.62 (1.83)	1.42	6.67	4.60	-2.06

Note: values are presented as mean (± SD); Δ: pre- to post-training changes; †Significant 'Group x Time' interaction: significant effect of the intervention ($p < 0.001$). *Significantly different from pre-test ($p < 0.001$). n= number of shuttles; reps= number of repetitions; cm= centimeters.

MOTORFIT

Statistical analysis revealed a significant "Time x Group" interaction for Motorfit Locomotor ($F1_{,198} = 42.97$, $p < 0.001$, $\eta 2p = 0.87$, large effect size*) and Motorfit Object (*$F1_{,198} = 23.32$, $p < 0.001$, $\eta 2p = 0.88$ large effect size). Post-hoc analysis revealed a positive for Motorfit Locomotor *($t = 12.40$*, $p < 0.001$, $d = 0.98$, large effect size) and Motorfit Object ($t = 18.31$, $p < 0.001$, $d = 1.44$, large effect size*)* in the *intervention group*. No significant changes were found for the control group ($p > 0.05$).

AC-MT 11-16 Test

Statistical analysis showed significant 'Time x Group' interaction for *AC-MT 11-16 Test* in three of four macro-variables, namely Comprehension and production ($F_{1,198} = 37.71$, $p < 0.001$, $\eta^2_p = 0.86$, large effect size), Arithmetic reasoning ($F_{1,198} = 20.37$, $p < 0.001$, $\eta^2_p = 0.93$ large effect size), and Problem solving ($F_{1,198} = 62.31$, $p < 0.001$, $\eta^2_p = 0.93$, large effect size). The post-hoc analysis revealed a significant improvement in the EG score for Comprehension and production ($t = 5.92$, $p < 0.001$, $d = 0.86$, large effect size), Arithmetic reasoning ($t = 7.12$, $p < 0.001$, $d = 0.95$, large effect size), and Problem solving ($t = 10.41$, $p < 0.001$, $d = 0.92$, large effect size). No significant changes were found for the control group ($p > 0.05$).

4. Discussion

The current investigation sought to explore the efficacy of a Physical Literacy (PL) program on the motor skills and cognitive abilities of children. The findings indicated that the implementation of a PL program exerted a favorable influence on both physical and academic outcomes among first-grade middle school students. This impact was found to be more pronounced for the PL program in contrast to conventional lessons that merely incorporated basic physical training devoid of cognitive engagement. Consequently, the results of this study appear to align with existing literature which posits that physical activity (PA) that necessitates cognitive effort yields advantageous effects on educational outcomes through the incorporation of PL domains (Durden-Myers, Bartle, Whitehead, & Dhillon, 2022).

It is posited that this phenomenon may be elucidated by the premise that PL fosters the child's concentration on tasks, enhances their capacity to focus on objectives, and promotes swift reaction capabilities (Whitehead, 2020). In contrast, the uncomplicated physical exercises provided in this study merely required students to recall previously acquired information and apply it to subsequent movements and tasks, where the emphasis was placed more on the repetition of movements rather than on the depth of cognitive engagement (Scott, Hill, Barwood, & Penney, 2021). Numerous scholars assert that the difficulties encountered in the learning process are significantly influenced by the relevance and dominance of particular cognitive processes, such as memory, attention, psychomotor skills, and visual-perceptual factors, all of which may be influenced by physical activity that involves cognitively engaging tasks (Young, O'Connor, & Alfrey, 2020). Importantly, the prevailing body of evidence substantiates the assertion that PL can substantially enhance academic performance in children, as they exhibit improved speed and precision in completing various cognitive tasks (e.g., on-task behavior, executive function skills, and academic achievement) subsequent to engaging in a session of physical activity (Martins et al., 2021).

Additionally, empirical research has elucidated that Physical Literacy (PL) significantly contributes to improvements in academic performance, attributable to its efficacy in facilitating the allocation of cognitive resources that are essential for executing tasks that require working memory (Istiadah, & Permana, 2023). These results suggest that PL is integral to the promotion of physically active lifestyles. PL functions as a crucial framework for imparting fundamental knowledge, skills, physical fitness, and positive attitudes that are indispensable for individuals to evolve into adept movers and proficient performers, which are vital for engagement in a broad spectrum of physical activities. PL provides a comprehensive range of physically engaging activities that are developmentally suitable and meaningful for students (Durden-Myers, Bartle, Whitehead, & Dhillon, 2021). It employs effective pedagogical strategies to deliver optimal educational experiences for learners and

to cultivate supportive learning environments. In essence, PL should not be confined to a singular focus on the critical area of physical health through athletic participation (Young, Alfrey, & O'Connor, 2023), but rather should aim to nurture in youth a cognitive-motor repertoire that evolves in harmony with the rhythms of personal development and the opportunities afforded by the environment (Wilkie et al., 2024). Indeed, by engaging in significant motor experiences that facilitate the development and structuring of fundamental motor patterns alongside their executive variations, it becomes achievable to attain mastery in increasingly complex motor skills. Viewed from this perspective, PL enables the embedding of significance into lived experiences by transforming bodies into "incubators" of knowledge (Young, O'Connor, Alfrey, & Penney, 2021).

Numerous theoretical frameworks have been documented that may elucidate the correlation between physical education (PE) and enhanced academic performance (Durden-Myers, & Bartle, 2023). Certain empirical research findings suggest that PE may exert direct beneficial effects on the central nervous system through the augmentation of cerebral volume, enhancement of cerebral blood flow, promotion of synaptic plasticity, and facilitation of neurogenesis, all of which are essential for various dimensions of perception, cognition, memory, and attentional processes (Choi et al., 2021). Additional analyses reveal that PE contributes positively to psychological metrics such as self-esteem, motivation, social engagement, and communication (Liu, & Chen, 2021), which are fundamentally crucial for realizing academic success. Furthermore, research indicates that inadequate motor competence may exert adverse effects on these psychological constructs and impede cognitive development. The findings illustrate a connection between elevated levels of physical activity and enhanced attentional capacity, the capacity to sustain concentration in academic contexts, and overall academic achievement (Quennerstedt, McCuaig, & Mårdh, 2021).

In the context of this inquiry, it is imperative to underscore that substantive physical education constitutes a fundamental element of superior physical education (Petrie, Pope, & Powell, 2021), and superior physical education intrinsically necessitates the application of a pedagogical approach that is informed by and augments physical literacy. High-quality physical education emphasizes the significance of physical literacy as a developmental benchmark that nurtures an individual's bodily awareness, physical proficiency, and enjoyment in participating in physical and motor activities.

Physical education constitutes the foundational and, in numerous contexts, the singular systematic structure through which students are afforded opportunities to engage in motor experiences that possess semantic and logical connections to various learning processes. Consequently, it significantly influences the advancement of the educational trajectory by fostering an awareness of the corporeal self, facilitating the acquisition of motor competencies, and augmenting both the quantitative and qualitative prospects for executing motor sequences, thereby allowing individuals to engage profoundly not solely on the physical-motor

plane but also on a cognitive level (Zengaro, & Zengaro, 2025). Within the sphere of pedagogical practice dedicated to the provision of high-quality physical education, particularly concerning the methodologies, instruments, and efficacy with which the objectives of the discipline are actively pursued, the interpretations and values attributed to the body, movement, and the proficiency with which the educator imparts skills relevant to physical literacy assume critical significance. Physical literacy provides a scholarly framework to guide the development of interventions. Concurrently, physical literacy has emerged as a central theme of research regarding the implementation of interventions for children and adolescents globally. This relationship is predicated on the premise that enhancements in physical literacy can positively influence self-efficacy and motivation related to the learning experience (Jean de Dieu, & Zhou, 2021). Consequently, it is reasonable to postulate that aspects of physical literacy may be interconnected with educational achievement across domains that transcend physical education. In addition to the essential educational significance of physical literacy, acknowledging this correlation can facilitate the establishment of educational frameworks grounded in physical literacy aimed at enhancing the comprehensive academic success of young learners (Bartle, 2023).

Although this research has elucidated the efficacy of physical literacy (PL) in fostering both motor and cognitive developmental trajectories in children, several limitations warrant acknowledgment. First and foremost, the extant literature is predominantly limited to participants from a singular geographic locale, thereby constraining the applicability of the findings to a more expansive student demographic. Furthermore, a significant shortcoming is apparent in the examination of the longitudinal effects associated with the intervention. In addition, the study is characterized by a narrow age range, and the data was collected during a singular temporal context. Finally, recognizing that physical literacy (PL) constitutes a pivotal educational dimension, the relationship between PL and academic achievement may vary across diverse cultural and educational landscapes; hence, investigating its manifestation among students worldwide could provide valuable insights into this subject matter. Consequently, it is recommended that future research endeavors investigate similar variables within a more extensive and varied sample, encompassing educators and learners across primary, secondary, and tertiary educational levels. Nevertheless, the findings obtained may offer significant implications for subsequent scholarly inquiries. Therefore, the merits of this study were enhanced by this adept methodology that promotes the elevation of Physical Education quality within our educational institutions.

Conclusions

Physical Literacy, considered as a background that gives meaning to the education of movement and corporeality, represents a crucial junction in school curricula. At the same time, it represents one of its fundamental purposes of physical education, because it expresses the degree of competence, autonomy and responsibility through which an individual chooses, plans and practices physical and sporting activities in a conscious way. The purposes of physical education, as a school discipline, and of the education of corporeality and movement, understood in its broadest sense, should allow the acquisition of all those capabilities that allow the individual to choose with responsibility and autonomy a physical or sporting activity appropriate to his or her physical and health conditions, to lead a healthy and active lifestyle aimed at achieving and maintaining a sense of well-being total.

In this perspective, it becomes of paramount importance that school interventions aim at the holistic improvement of students, as well as maintaining a multi-component structure (e.g., involving physical education and other subjects, families, etc.). In this line, as opposed to approaches whose sole purpose is to increase the volume of physical activity, physical literacy seeks to develop knowledge and understanding of how, why and when people move, and the social skills to be active with others.

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